SELECTIVE WET-ETCHING OF GESI IN MULTI-LAYER GESI/SI STACKS

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ABSTRACT

In this paper, the channel release process of stacked gate-all-around (GAA) nanosheet (NS) devices fabricated based on the epitaxial scheme is investigated extensively. The effects of annealing temperatures, thicknesses of the GeSi layers and liquid nitrogen processing on the wet selective etching of GeSi in multi-layer GeSi/Si samples are mainly studied. It is found that the corrosion rate of the GeSi in GeSi/Si stacks samples first decreases and then increases with the increasement of rapid thermal annealing (RTA) temperatures, and the corrosion rate is the slowest at 600℃. In addition, the thicker the epitaxial GeSi, the faster the corrosion rate. Furthermore, we found that the corrosion rate of the samples after liquid nitrogen processing treatment was faster than that without treatment. The research provides a good reference significance for the design and manufacture of advanced stacked GAA Si NS devices.

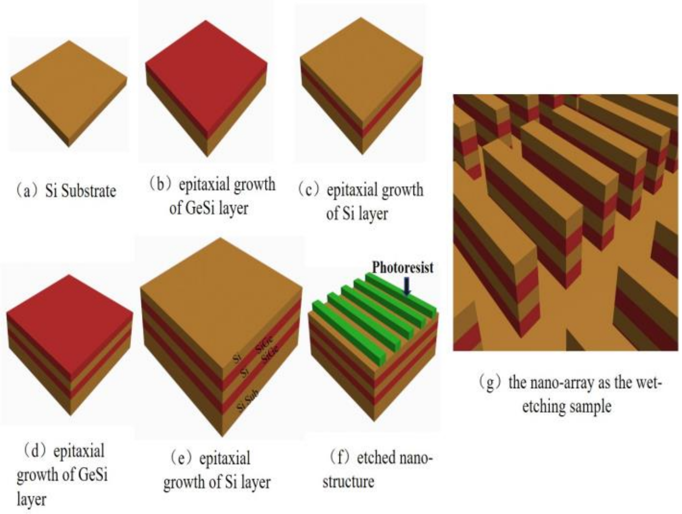
INTRODUCTION

With continuous scaling integrated circuits (ICs) along the Moore's law, Conventional fin field effect transistors (FinFET) devices faces more complex fabrication process, non-uniform threshold voltage and serious mobility degradation[1-4]. stacked gate-all-around (GAA) Si nanosheet (NS) FET has been considered as one of the most promising candidates for 3nm node and beyond[5-7]. However, the stacked GAA Si NS FET also faces many challenges, such as selective Si NS channel release, new stack parasitic channel suppression approach and the risk of Ge contaminations[8].

In this paper, the effect of the rapid thermal annealing (RTA) temperature and thickness of GeSi layer on selective wet-etching of GeSi in GeSi/Si layer was studied in detail. It is found that the corrosion rate of the GeSi layer in laminated samples first decreases and then increases with the increasement of RTA temperatures, and the thicker the epitaxial GeSi, the faster the corrosion rate. In addition, we found that the corrosion rate of the samples after liquid nitrogen processing treatment was faster than that without treatment.

EXPERIMENTAL

8 inches *p*-type Si <100> wafers were used with 8-12 Ω•cm resistivity. The wafers was load into a ASME2000 plus pressure reduced pursue chemical vapor deposition (RPCVD) tool for epitaxial growth of multi-layer GeSi/Si stacks after removing the native oxide (see fig 2 (e)). In order to observe and analyze the selective etching results of multilayer GeSi/Si layes, a rectangular arrays with spacing of 4μm were formed by lithography and etching processes (see fig.1 (g)). After epitaxial of multi-layer GeSi/Si stacks, the samples was cut into small species and annealed at different RTA temperatures (500℃, 600℃, 700℃, 800℃,900℃ and 1000℃) for 30s. In the flowing step, a mixed solution of HF(6%)：H_2O_2(30%)：CH_3COOH(99.8%)=1:2:3 holding for 24 hours was used to etch the samples with different annealing temperatures and GeSi thickness [9]. The etched samples were characterized by scanning electron microscope (SEM) to observe the etching morphology and measure the etch depths.



（a）Si Substrate
（b）epitaxial growth of GeSi layer
（c）epitaxial growth of Si layer
（d）epitaxial growth of GeSi layer
（e）epitaxial growth of Si layer
（f）etched nano-structure
（g）the nano-array as the wet-etching sample

Fig.1 Fabrication flow of the stacked GeSi/Si samples

RESULTS AND DISCUSSION

Fig. 2 is SEM images of the corroded GeSi samples after different RTA temperatures and corresponding etching lengths of the GeSi layers is show in Fig. 3. As can be seen from the images, the etching lengths exhibits firstly decreases, and then increases with the increase of RTA temperatures. The corrosion rate is the slowest at 600 ℃ [10]. As the epitaxial growth temperature of GeSi/Si stacks is 650℃, it deviates from the growth temperature of epitaxial lamination regardless of high or low temperature annealing. The RTA annealing leads to part of the stress is released, which generates more defects at the GeSi/Si interface and increases the corrosion rate of GeSi layer. When the annealing temperature is 1000℃, the thickness of Si layer becomes thinner and exhibits a little "warping" (see fig. 2 (f)).

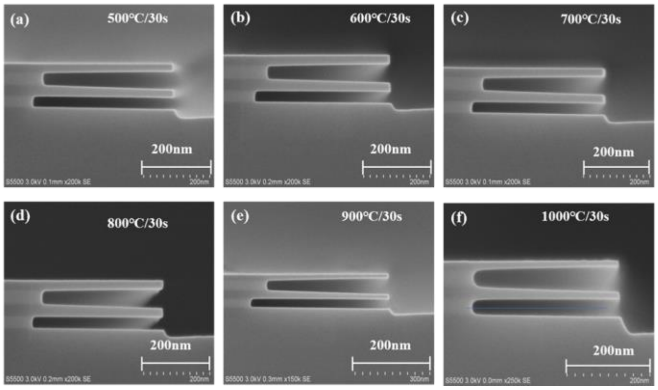


Fig.2 SEM images of the corroded GeSi samples after different RTA temperatures

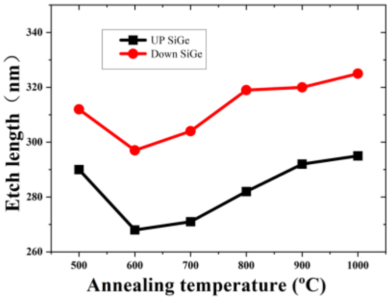


Fig.3 Variation of the corrosion depths of the GeSi layer after different RTA temperatures for 8 min.

In addition, the thickness of *GeSi* layer in the *GeSi*/Si stacks determines the spacing of the final stacked GAA Si NS channel, which would affect channel morphology and high-k/metal gate (HK/MG) filling. So the thicknesses of the GeSi layer (5nm, 10nm and 20nm) on the etching rate is also investigated, and the 20 nm Si layer acts as the interlayer between the GeSi layers. Fig.4 shows the SEM images of different corrosion times (1min, 3min, 5min, 7min, 9min, 11min and 13min, respectively) and the corresponding the etching lengths of different GeSi thicknesses as an function of the etching times is shown in Fig.5 As can been seen from the images, the thicker the epitaxial GeSi, the faster the corrosion rate. In addition, the longer Si layers after more corrosion of GeSi layer are prone to "adhesion", and the thiner GeSi layer is more prone to "adhesion" because a greater surface tension of the liquid in a narrow space [11-12].

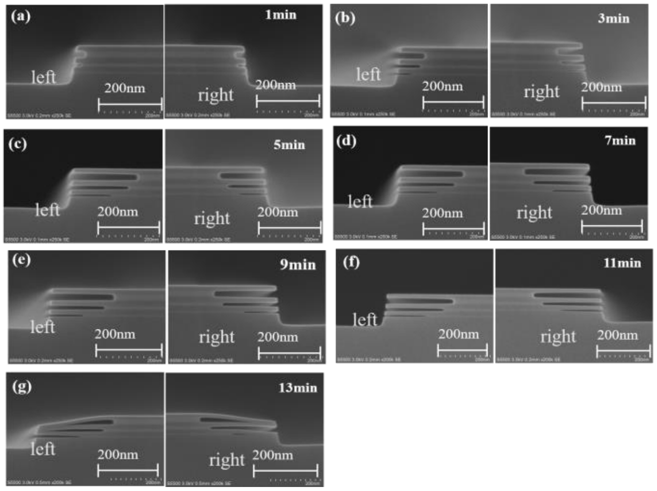


Fig. 4 SEM images of the corroded GeSi samples with different GeSi *thicknesses.*

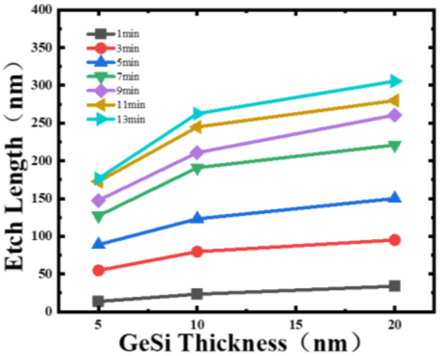


Fig. 5 Variation of the corrosion depth of the GeSi layer with different GeSi thicknesses.

The effect of liquid nitrogen processing on the selective corrosion of GeSi/Si layers was also studied. Then GeSi/Si samples after heated to 125℃, were put into liquid nitrogen processing rapidly. Finally, the samples treated with and without liquid nitrogen were corroded for 1min, 3min, 5min, 7min, 9min, 11min and 13min, and the SEM scanning figure as shown in fig.6 and fig.7, respectively. As can be seen from the images, both samples treated with and without liquid nitrogen achieve high selective ratio GeSi corrosion, but the corrosion footing effect after liquid nitrogen treatment is improved. Fig.8 shows the comparison of corrosion lengths with and without liquid nitrogen treatment. It can be seen that the etching depth with and without liquid nitrogen treatment is almost the same when the corrosion time is less than 2 min. However, the corrosion rate of samples treated with liquid nitrogen is faster than that without treatment when the etching time over 2 min. When the corrosion time exceed 8 min, the depth is greater than 300nm. The corrosion rates of both cavities begin to slow down because the reaction products in the deep cavity cannot exchange quickly, which limit the progress of the reaction. The above results shows that the thermal expansion coefficient of GeSi and Si materials treated with liquid nitrogen is different. The processing of liquid nitrogen caused the rupture of the GeSi/Si interfacial bond, resulting in a faster corrosion rate and improved the "footing" effect.

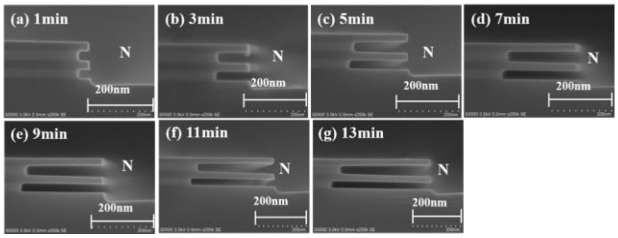


Fig.6 SEM images of stacked GeSi samples with different etching times after liquid nitrogen processing

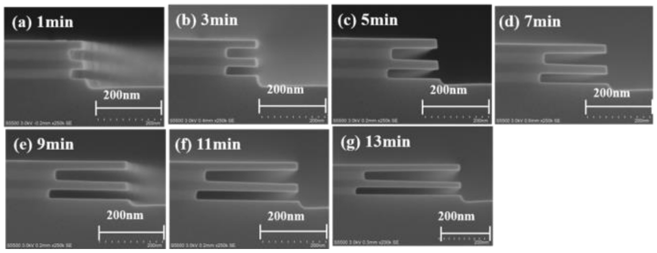


Fig.7 SEM images of stacked GeSi samples with different

etching times

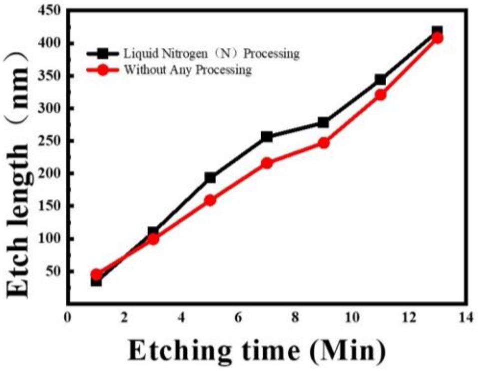


Fig.8 Corrosion of the depths of the GeSi layer with or without liquid nitrogen processing.

CONCLUSION

In this paper, the effects of annealing temperature and GeSi thickness on the etching of stacked GeSi/Si layers were investigated extensively. It is found that the corrosion rate of laminated samples first decreases and then increases with the increasement of rapid thermal annealing (RTA) temperatures, and the corrosion rate is the slowest at 600 ℃. It is also found that the thicker the epitaxial GeSi layer, the faster the corrosion rate. The effect of liquid nitrogen processing on the selective corrosion of GeSi/Si layers was also studied. The processing of liquid nitrogen caused the rupture of the GeSi/Si interfacial bond, resulting in a faster corrosion rate and improved L "footing". The research provides a good significance reference for the design and manufacture of advanced stacked GAA Si NS devices.

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